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Agricultural Experiment Station

Reaction of Barley Varieties to Helminthosporium Sativum

PART I. Varietal Resistance

PART II. Inheritance Studies in a Cross Between Lion and Manchuria

By

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UNIVERSITY FARM, ST. PAUL

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By H. K. Hayes, E. C. Stakman, Fred Griffee, and J. J. Christensen

PART I. VARIETAL RESISTANCE

INTRODUCTION

Spot blotch disease of barley was mentioned by Pammel (7) in 1909 and was attributed to *Helminthosporium sativum* Pammel, King and Bakke (8) in 1910. Christensen (1) has reviewed previous studies relating to the pathogeneity of *H. sativum* and has pointed out that the parasite is responsible for "leaf spot, root-rot, foot-rot, and seedling blight of wheat, barley, rye, and numerous grasses." Because the organism is so widely distributed and appears to be progressively more destructive, it seems necessary to take steps to control it.

The initial infections under field and greenhouse conditions come from seed or from soil (1). While partial control may be obtained by seed treatment [Louise J. Stakman (10)], good cultural methods, and rotation, the results so far obtained indicate that the use of resistant varieties is by far the most promising means of control.

A preliminary report has been made (6) of the comparative susceptibility of barley varieties and purified hybrids under field conditions at the Minnesota Agricultural Experiment Station. From the results of this study it appeared that there was no close correlation between the mode of reaction of a pure line of barley to *H. sativum* and its botanical or agronomic characters.

The degree of injury caused by *H. sativum* to any variety appeared to be strongly influenced by the environmental conditions under which the crop was produced. In other words, resistance or susceptibility is a relative character and is not absolute. Therefore the disease can best be controlled by combining correct cultural practices with the use of resistant varieties. The purpose of this paper is to present evidence on the comparative resistance of a considerable number of varieties of the four barley species groups. A study also was made of methods of determining the comparative mode of reaction of barley varieties to infections of the causal organism.

The study is a part of co-operative investigations carried on by the sections of plant breeding and of plant pathology which have as their aim the production of disease-resistant varieties of field crops that are also adapted to Minnesota conditions.

MATERIAL AND METHODS

The varieties used in the study were obtained from the material under test in the co-operative barley breeding studies carried on by the plant breeding section of the Minnesota Agricultural Experiment Station and the Office of Cereal Investigations of the United States Department of Agriculture. Most of the varieties used, with the exception of certain hybrids, were obtained originally from the Office of Cereal Investigations, and for this reason are reported under the classification groups as outlined by Harlan (2).

For the field tests of mode of reaction of the varieties, five-foot rows were planted at the rate of 5 grams of seed per row.

The varieties were grown in infested soil and were sprayed at about heading time, at intervals of a day or two, with spore suspensions of *H. sativum.*

The spraying was done between 7 and 8 p.m., from three to five sprayings being made.

Data on the degree of infection were taken when the barley was nearly mature. Separate notes were taken on the degree of infection of heads, culms and nodes, and roots. The terms "heavy," "medium," "light," and "trace," were used to denote degrees of infection; and plus and minus signs further to differentiate the severity of the infection. For more exact comparison, the various degrees of infection were denoted by numerical figures as follows:

trace = 10	medium — = 6	heavy — = 3
light — = 9	medium = 5	heavy = 2
light = 8	medium + = 4	heavy + = 1
light + = 7		

These figures allowed a summary of the infection of the separate notes taken on three different parts of the plants, i.e., spike, culm and leaves together, and root, and also aided in determining the degree of correlation between reactions obtained in successive seasons or between the degree of infection of different parts of the plants of the same varieties.

INJURY DUE TO HELMINTHOSPORIUM SATIVUM

Thirty-nine purified smooth-awned strains of barley produced from crosses were grown in replicated rod-row trials in 1921 and 1922. The same strains were grown also for the same years in single five-foot rows and were sprayed with spore suspensions of *H. sativum.*

The rod-row trial plots are grown on series which are under rotation, the cropping plan being as follows: Rye, clover in spring, clover hay, rod-row test of small grains, ear-to-row tests of corn, peas for seed, soybeans, rod-row test of small grains, etc. The legume crops

and the cultivation of the corn help to keep the soil in good condition.

The nursery in which the mode of reaction to *H. sativum* was studied was on the same plot each of the three years that the study was carried on.

The calculation of the correlation between average yields as obtained in the rod-row trials, and average reaction to *H. sativum* under artificially induced epidemic conditions, furnishes an opportunity to determine the importance of the pathogene in reducing yields. The smooth-awned hybrids furnished ideal material for this study, as they were obtained for the most part from crosses in which one of the parents was resistant and the other susceptible to attacks of the spot blotch disease. The obtained coefficient (see Table I) $+.445\pm.087$ is more than four times the probable error and indicates that susceptibility to *H. sativum* tends to reduce yield. The correlation proves that, under the conditions of the experiment, resistance to *H. sativum* is a character which must be considered by the barley breeder and by the crop producer.

Seventeen 6-rowed strains and varieties of barley were grown for the three-year period, 1919-22, in a replicated rod-row trial. The average yield obtained was correlated with the average reaction to *H. sativum* for 1921-22 (see Table II). The obtained coefficient $+.575\pm.109$ is again probably statistically significant and furnishes further evidence regarding the importance of resistance to *H. sativum*.

TABLE I

CORRELATION IN SMOOTH-AWNED BARLEY HYBRIDS BETWEEN AVERAGE YIELDS FOR 1921-22, IN BUSHELS PER ACRE, IN REPLICATED ROD-ROW TESTS AND AVERAGE REACTION TO *H. sativum* UNDER ARTIFICIALLY INDUCED EPIDEMIC CONDITIONS

Average Helminthosporium reaction	Average yield: 42	45	48	51	54	
12	1					1
15	1	3	1		1	6
18	2	1	4	2		9
21		2	8	6	2	18
24		1	2		2	5
	4	7	15	8	5	39

$r = .445\pm.087$

TABLE II

CORRELATION IN SIX-ROWED BARLEY STRAINS BETWEEN AVERAGE YIELD, IN BUSHELS PER ACRE, 1920-22, AND AVERAGE REACTION TO *H. sativum* FOR 1921-22 UNDER ARTIFICIALLY INDUCED EPIDEMIC CONDITIONS

Average Helminthosporium reaction	Average yield 30	35	40	45	50	55	
5	1	1					2
10			1	1	1		3
15			2		1		3
20		1	1	3	3		8
25						1	1
	1	2	4	4	5	1	17

$r = .575 \pm .109$

RESISTANCE OF VARIETIES OF BARLEY TO ATTACKS OF H. SATIVUM UNDER FIELD TEST

A considerable number of varieties of barley have been grown for several years in five-foot rows and an epidemic of spot blotch disease has been produced artificially by spraying the varieties with spore suspensions of *H. Sativum*. The results of the three-year trials are presented in Table III.

In 1920 infection data were taken only on the culm and on the spike and node together. Severity of infection was denoted by average infection. In 1921 and 1922 separate notes were taken upon the degree of infection of spike, foliage, i.e., culm and nodes, and roots, and the results were summarized under the heading "Numerical figure." As was explained under "materials and methods," a high figure, of which 30 is the maximum, denotes very high resistance, while a low figure, of which 3 is the minimum, denotes complete susceptibility.

In the second column of the table the species group is given.

The barley varieties were planted rather late in 1921 and all were much more severely infected than in 1922, when they were planted early in the season. In general, however, varieties that were susceptible one year were likewise susceptible the following year, while those that were resistant one year appeared resistant the following year.

Twelve different pure lines of Manchuria barley were grown in each of the three years. All appeared rather resistant except Manchuria, C 81, which was the most susceptible of the twelve strains in both 1921 and 1922. It seems reasonable to conclude that this strain of Manchuria barley is more susceptible than other strains.

Apparently, therefore, strain differences within the same variety may be of considerable importance.

TABLE III

REACTION OF BARLEY VARIETIES TO *H. Sativum* UNDER ARTIFICIALLY INFUCED EPIDEMIC CONDITIONS*

Variety name		Species group	Reaction to Helminthosporium										Average numerical figure, 1921 and 1922
			1920	Numerical figure	1921				1922				
					Spike	Foliage	Roots	Num. fig.	Spike	Foliage	Roots	Num. fig.	
		Vulgare											
Manchuria	Minn. 184	H.B.W.R.	L	8	M	M	M+	14	T	L	T+	28	21
	I-16-32	"	L	8	M—	M—	H—	15	T	L—	L—	28	22
	I-16-21	"	M—	6	L+	L+	H—	17	T	L—	T+	29	23
	I-16-29	"	M	5	M—	M—	M+	16	T+	T+	T+	30	23
	I-16-44	"	T+	10	M	M+	M	14	T	T	T+	30	22
	I-16-66	"	L	8	M—	M	H—	14	T	T+	T+	30	22
	I-15-1	"	L	8	L+	M—	M+	17	T	L+	L—	26	22
	I-15-2	"	L	8	M	M	H—	13	T	L	L—	27	20
	C 81	"	L+	7	M+	H—	H—	10	L	M+	L	22	16
	C 96	"	L	8	M—	M	H—	14	T	T	T	30	22
	C 163	"	L+	7	M	M	M	15	L—	L	T+	27	21
	C 168	"	L+	7	M+	M+	M+	12	L—	L	T+	27	20
Bay Brewing×Lion	C 225	"	H	2	H—	H	H—	8	H	H+	H	5	7
Trebi	III-20	"	H	2	M+	H—	M+	11	M	M+	M+	13	12
Trebi	I-16-14	"	M	5	H—	H	H	7	L+	M+	L	19	13
Coast	III-20	"	M+	4	M	H	M—	13	H	H	H	6	10
Winter Club	III-20	"	M—	6	M+	H	M	11	L	H	H	12	12
Beldi	III-20	"	M+	4	M+	H—	M+	11	H	H—	M	10	11
Mariout	III-20	"	H+	1	H	H+	H	5	H+	H	M—	9	7
Mariout	III-15	"	H+	1	H	H	H—	7	H	H	H	6	7
Servian	III-20	"	H	2	M+	H—	H—	10	L—	L	L+	24	17
Servian	I-16-15	"	H—	3	M	M	H—	13	L	M	L	21	17
C. I. 894	I-16-84	"	L	8	M—	M	M	16	L+	T	L+	24	20
Scotch	I-16-45	"	L	8	L	L	M	21	M	M	L+	17	19
Sandrel	I-16-3	"	M+	4	H—	H—	H	8	M	H	M	12	10

TABLE III—*Continued*

REACTION OF BARLEY VARIETIES TO *H. sativum* UNDER ARTIFICIALLY INDUCED EPIDEMIC CONDITIONS

Variety name		Species group	Reaction to Helminthosporium										Average numerical figure, 1921 and 1922
			1920	Numerical figure	1921				1922				
					Spike	Foliage	Roots	Num. fig.	Spike	Foliage	Roots	Num. fig.	
		Vulgare											
Odessa	I-18-2	H.B.W.R.	H—	3	L	L+	M	20	L	M—	L+	21	21
Luth	C 93	"	L	8	M—	M	M	16	T	T	T	30	23
Sandrel	C 104	"	L+	7	H—	H	M+	9	M	H—	H	10	10
Peruvian	III-20	"	H	2	H—	H—	H—	9	M—	M+	H	12	11
Arequipa	C 267	"	H—	3	†	†	†	3	M—	H	M	13	8
Minsturdi	II-16-47	"	M	5	L+	M	M	17	L	L	L—	25	21
S. Afr.×Manch.	II-16-77	"	M	5	M+	M+	H—	11	L	M	L	21	16
Highland Chief	I-16-31	H.B.W.S.	M—	6	L+	L+	M+	18	T	M+	L+	21	20
Smooth Awn	C 284	"	H	2	L+	M+	M+	15	H—	M+	M+	11	13
Bay Brewing	I-18-3	H.B.B.R.	M—	6	X	H+	H+	3	H—	H+	H	6	5
Gatami	III-20	"	L	8	H	M+	H	8	H—	M+	M+	11	10
Lion	III-20	H.B.B.S.	H	2	H—	M+	H	9	H—	H—	M	11	10
	I-16-13	"	H+	1	H	M+	H—	9	M+	H	M	11	10
	C 270	"	H—	3	H—	H—	H—	9	H—	H	H	7	8
Horsfords	III-20	H.H.W.	M—	6	†	†	†	..	L	L+	L—	24	24
H. v. horsfordianum		H.H.W.	..	..	L+	M	L	20	L	L	T+	26	23
H. v. aethiops		H.H.B.	..	..	M+	M+	H	10	L	M—	L+	21	16
Himalaya	III-20	N.B.W.R.	M+	4	H	H	H	6	H	H—	H	7	7
H. v. coeleste		N.B.W.R.	..	..	M+	M+	M	13	T	L—	L+	26	20
Black Hull-less		N.B.B.R.	..	..	M—	H—	M+	13	T	L—	L+	26	20
Nepal	III-20	N.H.W.	M+	4	X	M+	M	14	T	L	T+	28	21
		Intermedium											
H. i. nudihaxtoni		N.B.W.R.	..	..	L+	H—	H+	11	M	M+	M	14	13
H. i. nudimortoni		N.B.B.R.	..	..	H—	H—	M+	10	L+	M+	L—	20	15
H. i. cornutum		N.H.W.	..	..	X	X	H+	3	T	H+	M+	15	9

* Distinct rosetting; symptoms similar to those caused by the so-called take all or rosette disease.

† Discarded.

TABLE III—*Concluded*

REACTION OF BARLEY VARIETIES TO *H. Sativum* UNDER ARTIFICIALLY INDUCED EPIDEMIC CONDITIONS

Variety name		Species group	Reaction to Helminthosporium										Average numerical figure, 1921 and 1922
			1920	Numerical figure	1921				1922				
					Spike	Foliage	Roots	Num. fig.	Spike	Foliage	Roots	Num. fig.	
		Distichon											
Hanna C. I. 906	III-20	H.B.W.R.	..	..	..	..	..	..	T	L	T+	28	28
Hanna	III-20	"	L+	7	L+	M+	M—	17	L+	M	L+	19	18
Hannchen	III-20	"	L	8	M—	M+	M+	14	L+	L+	L	22	18
Boltons	III-20	"	L—	9	M—	M	M	16	T	T	L+	27	22
Svanhals	I-13-21	"	L+	7	L	M	M	18	T	M—	L+	23	21
Boh. × Svanhals	II-16-78	"	L+	7	M	H—	M+	12	T	L	L	26	19
Svansota	II-16-37	"	M—	6	L+	M—	M+	17	T	M	T+	25	21
Chevalier	Minn. 230	"	..	..	..	..	..	..	T	L	L	26	26
Chevalier	III-20	"	L	8	M—	M—	M	17	L	M+	M	17	17
Wh. Smyrna		H.B.W.S.	M—	6	M+	M—	H—	13	T	M+	M	19	16
H. d. n. persicum	C.I. 1003	H.B.B.R.	..	..	L	L	M—	22	L	L+	M—	21	22
H. d. n. persicum	S.P.I. 38316	H.B.B.S.	..	..	M	M—	M+	15	L	L+	M—	21	18
Poppenheim		N.B.W.R.	..	..	L+	H—	M	15	T	L—	T+	29	22
H. d. nigrinudum		N.B.B.R.	..	..	H—	H	H—	8	L	H	M	15	12
H. d. laxum		N.H.W.	..	..	L+	M+	M	16	L	M	M	18	17
H. d. nigrilaxum		N.H.B.	..	..	H+	H+	H	4	L+	M+	L	19	12
		Deficiens											
H. def. deficiens	C.I. 6684		..	..	M—	M	L+	18	M—	L	L+	21	20
H. def. deficiens		H.B.W.R.	..	..	M	H—	L+	15	L+	M—	L+	20	18
H. def. steudelii		H.B.B.R.	..	..	L	H—	M	16	L	M—	L+	21	19
H. def. tridax		H.H.B.	..	..	M—	M+	M	15	L	L+	L—	24	20
H. def. nudideficiens		N.B.W.R.	..	..	M—	H—	H—	12	L+	H—	H	12	12

In the species group column H and N stand for hulled and naked seed; B and H stand for bearded and hooded; B and W stand for black and white; R and S stand for rough and smooth awn. Under Helminthosporium reaction T, L, M, and H stand for trace, light, medium, and heavy infection.

It is not necessary to discuss in detail the behavior of each of the varieties tested, but the reaction of some of the more important commercial varieties will be briefly mentioned.

Trebi, which appears in the table as III-20 and I-16-14, is a pure line resembling Coast. In describing Trebi barley, Harlan and others (4) said "The variety was not especially well adapted to Minnesota. . . . At Aberdeen the variety was in the first rank in the nursery from the beginning. It is especially adapted for irrigated conditions." Trebi has yielded well at University Farm, St. Paul, Minn., but it is very susceptible to attacks of *H. sativum*.

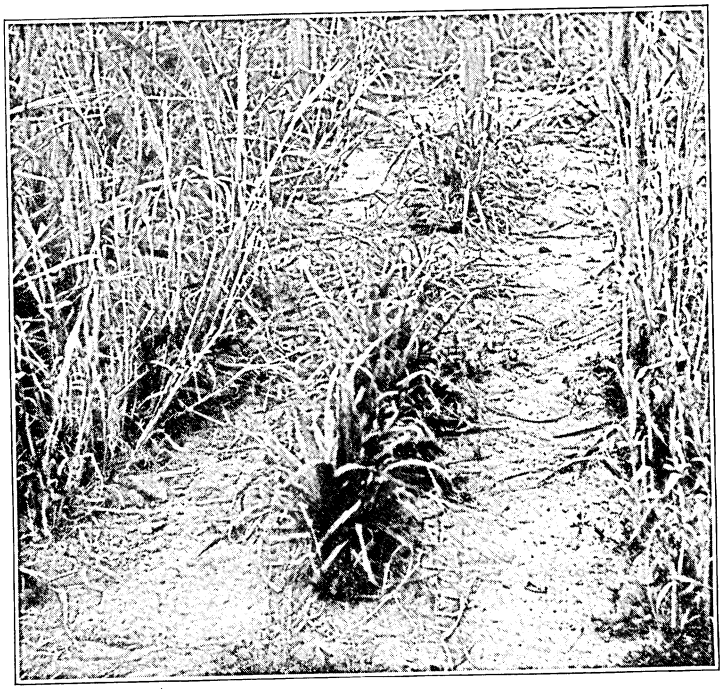

Fig. 1. Varietal Differences in Resistance to *Helminthosporium sativum*, Harvest Time, 1921
At left, Manchuria, Minn. No. 184, resistant; in center, Arequipa, very susceptible; at right, Lion, susceptible.

The new 6-rowed variety, Minsturdi, recently increased by the Minnesota station, appears resistant. It also excels in strength of straw and yield. It is particularly adapted to Southern Minnesota conditions.

In the 6-rowed group, Mariout and Bay Brewing are extremely susceptible to *H. sativum;* while Lion, the smooth-awned, black, 6-rowed variety, is rather susceptible. Gatami, the black, 6-rowed variety, appears susceptible.

The hooded-hulled, white variety, Horsford Beardless, appears resistant.

In the naked, bearded, 6-rowed group, the variety Himalaya (Guy Mayle) appears susceptible, while Black Hull-less appears resistant. Nepal, the naked, hooded, white barley, is resistant.

Three barleys belonging to the *Hordeum intermedium* species group showed considerable susceptibility.

In the *Hordeum distichon* group, Hanna, Hannchen, Svanhals, Boltons, Chevalier, and Svansota appear resistant. These are hulled, bearded, white, rough-awned varieties. Svansota was produced from a cross of an unnamed United States Department of Agriculture variety and Svanhals. It appears especially adapted to the region around Duluth, Minn., and is being distributed for use in this area.

In the *Hordeum deficiens* group both susceptible and resistant varieties have been found.

To determine the accuracy of the estimate of resistance by the reaction as obtained in a single five-foot row, the resistance or susceptibility as obtained for the various years of the study was expressed numerically. Correlation coefficients were computed for the purpose of showing the extent to which resistance or susceptibility was an inherited character. As has been previously noted, environmental conditions widely modify the extent of infection. This was very evident in the variety test carried on at Grand Rapids in 1921. One side of the field stood under water early in the spring and the soil was somewhat over-supplied with moisture late in the season. The barley on this area was much more severely infected with spot blotch than that on the better drained parts of the field.

The notes taken in 1920 were on the basis of the average infection of the varieties, while in 1921 and 1922 separate notes were taken on the infection of spikes, foliage, and roots of each variety. Correlation coefficients have been calculated which express the relation between the infections for successive seasons. If a variety was resistant one season and susceptible the following year the hope of controlling attacks of *H. sativum* by use of resistant varieties would not be very great. The correlation coefficients for the infection in 1920 as compared with 1921, and for 1921 as compared with 1922 are given in Tables IV and V. The coefficients are $.497 \pm .073$ and $.616 \pm .051$. These coefficients show that heredity plays an important part in the extent to which a variety is infected. They likewise prove that a test for a single season in a single five-foot row, even when the varieties are artificially sprayed with *H. sativum*, is not sufficient to ascertain whether a variety is resistant or susceptible.

TABLE IV

CORRELATION BETWEEN DEGREE OF INFECTION OF 49 BARLEY STRAINS OR VARIETIES FOR 1920 AND 1921

Degree of infection, 1920	Degree of infection, 1921							
	3	6	9	12	15	18	21	
1		2	1					3
2	1		4		1			6
3	1		1	1			1	4
4		1	2	2				5
5		1		1	1	1		4
6	1			2		3		6
7			2	2	1	2		7
8			1	1	7	2	1	12
9					1			1
10					1			1
	3	4	11	9	12	8	2	49

$r = .497 \pm .073$

TABLE V.

CORRELATION BETWEEN THE DEGREE OF INFECTION OF 67 BARLEY STRAINS OR VARIETIES FOR 1921 AND 1922

Degree of infection, 1921	Degree of infection, 1922									
	6	9	13	15	18	21	24	27	30	
3	1		1	1	1					4
6	2	1	1							4
9	2	1	5	1		3	1			13
12	1	1	3	1	1	2		5		14
15			1		2	3	2	5	6	19
18					2	2	3	1	1	9
21					1	2		1		4
	6	3	11	3	7	12	6	12	7	67

$4 = .616 \pm .051$

METHODS OF STUDYING MODE OF REACTION TO H. SATIVUM

While the determination of the resistance of susceptibility of varieties of barley was the primary aim of the study, little was known regarding the better means of carrying on the tests. For this reason it seems desirable to present certain facts which show some of the diffi-

culties of the study and which likewise indicate the degree of accuracy with which the facts of resistance or susceptibility may be reached through a single season's trial.

It has been noted that separate notes were taken in 1921 and 1922 on the average infection of spike, foliage, and roots of the varieties in the test. Correlation coefficients have been calculated which denote the behavior of the varieties in two successive years. They are given in Tables VI to VIII inclusive.

TABLE VI

CORRELATION BETWEEN DEGREE OF SPIKE INFECTION OF 63 BARLEY VARIETIES OR STRAINS FOR 1921 AND 1922

Degree of infection, 1921	Degree of infection, 1922										
	1	2	3	4	5	6	7	8	9	10	
1							1				1
2	1	2	1	1							5
3		1	2		2	1	2	1			9
4		1			1			4	2	3	11
5			1				1	2	1	4	9
6						1	3	2		6	12
7			1		1		1	3		5	11
8					1			3		1	5
	1	4	5	1	5	2	8	15	3	19	63

$r = +.488 \pm .065$

TABLE VII

CORRELATION BETWEEN DEGREE OF ROOT INFECTION OF 66 BARLEY VARIETIES OR STRAINS FOR 1921 AND 1922

Degree of infection, 1921	Degree of infection, 1922										
	1	2	3	4	5	6	7	8	9	10	
1		1		1	1						3
2		1		1	2	1	1	2			3
3		5			3		1	3	2	3	17
4		1		2	2	1	2	2	2	5	17
5		1			1		6		2	5	15
6		1				1	1				3
7							2				2
8										1	1
	10			4	9	3	13	7	6	14	66

$r = .298 \pm .076$

TABLE VIII

CORRELATION BETWEEN DEGREE OF FOLIAGE INFECTION OF 65 BARLEY VARIETIES OR STRAINS FOR 1921 AND 1922

Degree of infection, 1921	Degree of infection, 1922										
	1	2	3	5	5	6	7	8	9	10	
1	1	1		1							3
2	1	4	2	1							8
3		2	2	5		2		2	2		15
4		1	1	2	3	1	2	2	1	1	14
5					2	1		6		5	14
6				2			2		1	1	6
7				1		1			1		3
8					1			1			2
	2	8	5	12	6	5	4	11	5	7	65

$r = +.536 \pm .060$

The results show a coefficient of .488±.065 for the correlation between spike infection of the varieties grown in the two years of the test, .298±.076 for root infection, and .536±.060 for foliage infection. Apparently the infection of the foliage is a better criterion of the genetic nature of a variety in relation to resistance or susceptibility than is either spike or root infection.

The correlation obtained for average infection in 1921 in relation to that obtained in 1922, as has been previously noted, was .616±.051. This is slightly larger, altho not significantly so, than the coefficient obtained which shows the relation of spike and foliage infection for the two years.

Correlation coefficients were computed for 1921 and 1922 which show the extent to which an infection note on one part of a plant could be relied on to express the degree of infection which might be expected in another part of a plant of the same variety. The results of this study are presented in Table IX.

The calculated coefficients were larger in all cases for 1922 than for 1921. They were all between 0.7 and 0.8 in 1922, indicating the reliability of the notes taken on the separate parts of plants. In 1921 the coefficients were much smaller, showing that the amount of variability was greater in 1921 than in 1922 or that the experience gained in taking notes in 1921 aided in obtaining more accurate data in 1922. Results seem to justify taking separate notes on the degree of infection of separate parts of a plant as a means of determining whether a variety is resistant or susceptible.

TABLE IX

CORRELATION COEFFICIENTS WHICH EXPRESS THE EXTENT TO WHICH INFECTION IN ONE PART OF A PLANT MAY BE USED TO ESTIMATE THE INFECTION IN ANOTHER PART OF A PLANT OF THE SAME VARIETY

Subject	Relative	No. of strains or varieties	Year of test	Correlation coefficient
Spike infection	Root infection	64	1921	+.562±.048
Spike infection	Foliage infection	63	1921	+.646±.047
Root infection	Foliage infection	65	1921	+.362±.073
Spike infection	Root infection	70	1922	+.713±.040
Spike infection	Foliage infection	70	1922	+.709±.040
Root infection	Foliage infection	70	1922	+.782±.031

In the winter of 1922 an experiment was outlined to determine the possibility of using the greenhouse as a means of isolating varieties resistant to *H. sativum*. Ninety-eight varieties of barley were used. The study was carried in three series:

1. *Check series.*—The soil was steamed for four hours under 15 pounds pressure. The seed was disinfected in silver nitrate for four hours.
2. *Inoculated series.*—The soil and the seed were treated as in the check series. The medium containing the fungus was added to the soil before the seed was planted.
3. *Infected soil series.*—The soil used was obtained from the field in which the study of reaction of barley varieties to *H. sativum* was carried on. The soil was not sterilized and the seed planted was not inoculated.

Three pots of each variety were sown in Series 1 and 3 and four in Series 2. Twenty seeds each were sown in the pots of Series 3 and 25 in those of Series 1 and 2.

Data were taken on percentage of germination, number of seedlings killed, number of stunted seedlings, and degree of foot- and root-rot.

The value of the various notes in relation to the reaction of barley varieties under field trial was determined by correlating the field infection with the greenhouse results. The data are presented in Table X.

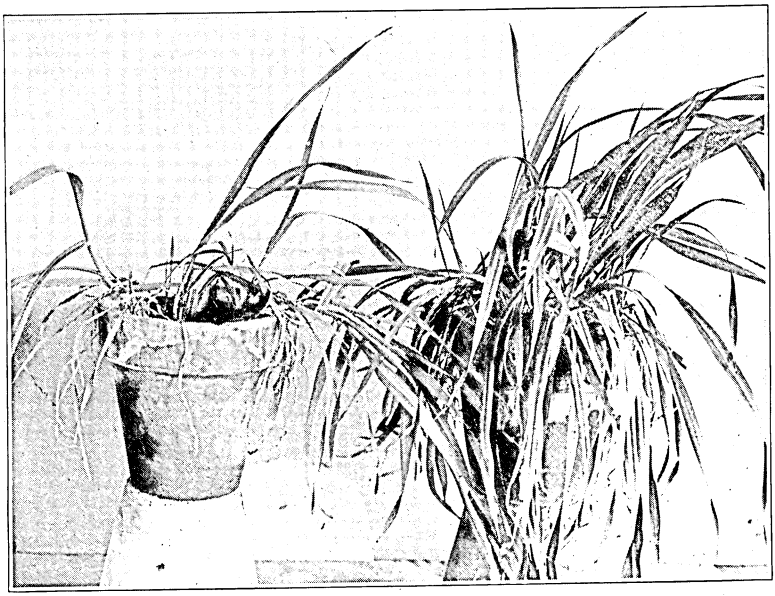

Fig. 2. Varietal Resistance in the Greenhouse, Inoculated Series, 1922-23
At left, Mariout III-15, very susceptible; at right, Manchuria, Minn. No. 184, resistant.

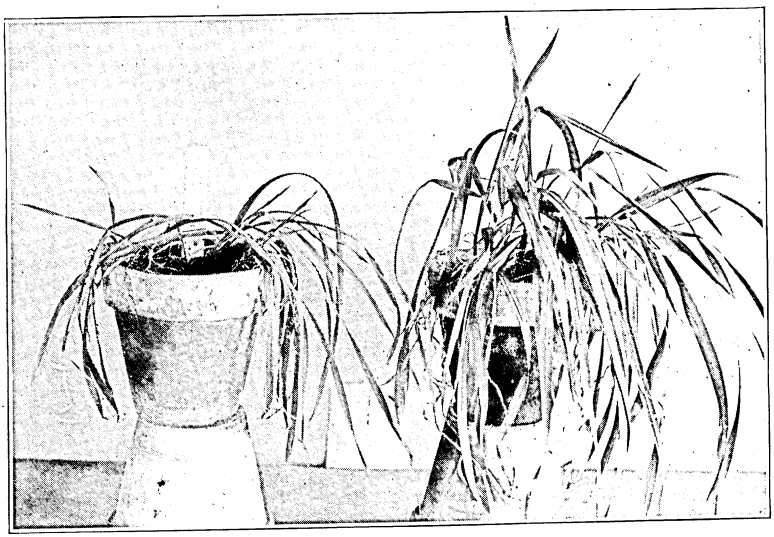

Fig. 3. Varietal Resistance in the Greenhouse, Infected Soil Series, 1922-23
At left, Lion I-16-13, susceptible; at right, Manchuria, Minn. No. 184, resistant.

TABLE X

CORRELATION COEFFICIENTS FOR INFECTION UNDER FIELD CONDITIONS IN RELATION TO INFECTION UNDER GREENHOUSE TEST

Subject	Relative	Correlation coefficient
Average root infection, 1921-22	Root infection, greenhouse. Average, series 1 and 2	+.341±.062
Root infection, 1922	Root infection, greenhouse. Average, series 1 and 2	+.414±.057
Average infection—root, spike, and foliage, 1921-22	Root infection, greenhouse. Average, series 1 and 2	+.373±.061
Average infection—root, spike, and foliage, 1921-22	Percentage seedlings killed, greenhouse. Average, series 1 and 2....	+.129±.067

These results show that the greenhouse trial may be used as an aid to the determination of the mode of reaction under field conditions. The correlations .341±.062, .414±.057, and .373±.061, which express the relation, respectively, between average root infection, 1921-22; root infection, 1922; and average infection of root, spike, and foliage 1921-22, as related to root infection under greenhouse conditions, are not significantly different. They are larger than the correlation for the degree of root infection for 1921 and 1922 which, as has been previously noted, was .298±.076. The correlations for root infection under greenhouse conditions with the average infection under field conditions are somewhat smaller than those for infection in separate years under field conditions when coefficients of .497±.073 and .616±.051 were obtained.

Apparently the number of seedlings killed is not very strongly correlated with the inherited mode of reaction of a variety to *H. sativum*.

COMPARATIVE RESISTANCE OF SMOOTH-AWNED STRAINS AND THEIR PARENTS

As has been noted in the study of reaction of barley varieties to *H. sativum*, the smooth-awned black variety, Lion, is susceptible. The importance of resistance to *H. sativum* was not appreciated when the original hybrids of Lion × Manchuria were made. The smooth-awned strains that were increased were soon found to be undesirable because of their susceptibility to spot blotch disease, and a new series was undertaken of crosses between various rough- and smooth-awned sorts. In all cases the smooth-awned parent used has been shown to be more susceptible to *H. sativum* than was Manchuria. In the F_3 and F_4 generations natural epidemics of *H. sativum* were obtained and there was an opportunity to select resistant types. The thirty-nine purified hybrids, all of which are smooth-awned types, have been

Fig. 4. Relative Reaction of Two Smooth-Awned Hybrids

At left, culms of Manchuria×Smooth-awned selection II-20-10, a resistant desirable type; at right, Arequipa×smooth-awned selection II-21-36, rather susceptible. Disease nursery, 1922.

grown for two years in replicated rod rows in the plant breeding nursery and under artificially induced epidemic conditions in five-foot rows in the plant pathology nursery. As has been pointed out, a correlation of $+.445 \pm .087$ was found between the yields obtained and the comparative reaction to *H. sativum*. Considering that a large number of susceptible forms were discarded from the trials, the correlation between yield and the reaction to the pathogene appears truly remarkable.

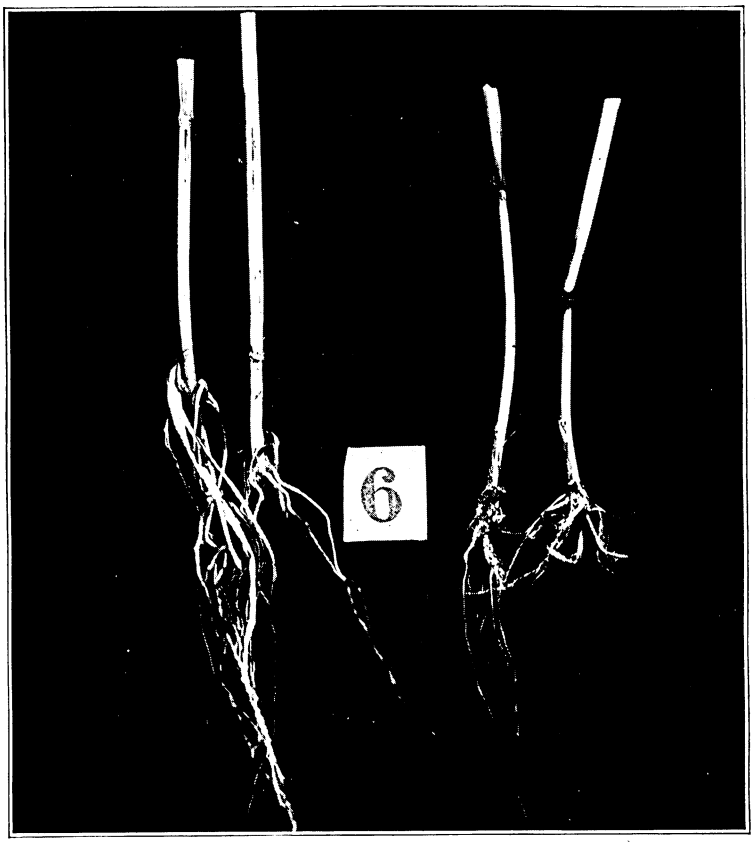

Fig. 5. Relative Reaction of Two Smooth-Awned Hybrids
At left, roots of II-20-10; at right, roots of II-21-36.

The data for average reaction to *H. sativum* and average yield per acre are given in Table XI. Many more than half of the smooth-awned hybrids are as resistant as the resistant Manchuria parents, altho a few strains appear rather susceptible. The smooth-awned parent, Culture 284, is a segregate from a previous Lion-Manchuria cross. It is a white-hulled variety and appears somewhat superior to Lion.

TABLE XI

REACTION TO *Helminthosporium sativum* UNDER INFECTION CONDITIONS, AND YIELD IN REPLICATED ROD-ROW TESTS OF SMOOTH-AWNED HYBRIDS AND THEIR PARENTS

Name	Nursery stock No.	Helminthosporium figure			Yield per acre, bushels		
		1921	1922	Average	1921	1922	Average
Manchuria (Culture 81)		10	22	16.0	31.7	56.9	44.2
Manchuria (Culture 96)		14	30	22.0	32.0	54.2	43.1
Manchuria (Culture 163)		15	27	21.0	30.0	64.2	47.1
Manchuria (Culture 168)		12	27	19.5	35.1	71.9	53.5
Manchuria (Culture 274)		16	26	21.0	27.3	74.0	50.7
Smooth Awn (Culture 284)		15	11	13.0	42.7	53.8	48.3
Manchuria × Smooth Awn (C96 × C284)	II-20-1	19	24	21.5	34.5	71.7	53.1
Manchuria × Smooth Awn (")	II-20-2	17	25	21.0	36.7	62.6	50.2
Manchuria × Smooth Awn (")	II-20-4	17	26	21.5	41.4	54.2	47.8
Manchuria × Smooth Awn (")	II-21-10	11	16	13.5	33.1	57.0	45.1
Manchuria × Smooth Awn (")	II-21-11	14	17	15.5	32.5	60.1	46.3
Manchuria × Smooth Awn (")	II-21-12	17	27	22.0	36.8	61.6	49.2
Manchuria × Smooth Awn (")	II-21-13	15	25	20.0	29.6	69.8	49.7
Manchuria × Smooth Awn (C168 × C284)	II-20-18	20	25	22.5	28.5	59.1	44.3
Manchuria × Smooth Awn (C163 × C284)	II-21-1	16	21	18.5	29.2	65.3	47.3
Manchuria × Smooth Awn (C81 × C284)	II-21-8	15	23	19.0	37.0	64.6	50.8
Manchuria × Smooth Awn (C81 × C284)	II-21-9	15	10	12.5	43.4	40.4	41.9
Smooth Awn × Manchuria (C284 × C274)	II-20-7	17	26	21.5	31.1	65.4	48.3
Smooth Awn × Manchuria (")	II-20-8	14	28	21.0	33.2	67.0	50.1
Smooth Awn × Manchuria (")	II-21-14	19	27	23.0	42.9	64.5	53.7
Smooth Awn × Manchuria (")	II-21-15	15	25	20.0	37.1	65.4	51.3
Smooth Awn × Manchuria (")	II-21-16	14	26	20.0	34.7	71.5	53.1
Smooth Awn × Manchuria (")	II-21-17	15	25	20.0	37.1	62.7	49.9
Smooth Awn × Manchuria (")	II-21-18	16	25	20.5	34.4	64.4	49.4
Smooth Awn × Manchuria (")	II-21-19	21	25	23.0	36.5	56.6	46.6
Smooth Awn × Manchuria (")	II-21-20	20	13	16.5	38.1	61.9	50.0
Smooth Awn × Manchuria (")	II-21-21	15	15	15.0	40.7	46.8	43.8
Smooth Awn × Manchuria (")	II-21-22	19	23	21.0	33.6	59.7	46.7
Smooth Awn × Manchuria (")	II-21-24	19	25	22.0	29.5	60.7	45.1
Smooth Awn × Manchuria (")	II-21-25	14	22	18.0	29.5	54.4	42.0
Smooth Awn × Manchuria (")	II-21-26	20	25	22.5	33.5	61.6	47.6

TABLE XI—*Concluded*

REACTION TO *Helminthosporium sativum* UNDER INFECTION CONDITIONS, AND YIELD IN REPLICATED ROD-ROW TESTS OF SMOOTH-AWNED HYBRIDS AND THEIR PARENTS

Name		Nursery stock No.	Helminthosporium figure			Yield per acre, bushels		
			1921	1922	Average	1921	1922	Average
Smooth Awn × Manchuria	(C284 × C274)	II-21-27	16	25	20.5	33.5	59.9	46.7
Smooth Awn	Culture 284		15	11	13.0	42.7	53.8	48.3
Luth	Culture 93		16	30	24.0	23.6	66.3	45.0
Smooth Awn × Luth	(C284 × C93)	II-20-9	16	26	21.0	33.2	67.6	50.4
Smooth Awn × Luth	(")	II-20-10*	14	29	21.5	32.4	66.2	49.3
Smooth Awn × Luth	(")	II-21-28	18	27	22.5	35.3	74.9	55.1
Smooth Awn × Luth	(")	II-21-29	19	23	21.0	33.0	64.0	48.5
Arequipa	Culture 267		1	13	7.0	23.1	40.5	31.8
Smooth Awn	Culture 284		15	11	13.0	42.7	53.8	48.3
Arequipa × Smooth Awn	(C267 × C284)	II-20-14	15	24	19.5	35.4	55.6	45.5
Arequipa × Smooth Awn	(")	II-21-34	17	21	19.0	31.9	51.8	41.9
Arequipa × Smooth Awn	(")	II-21-35	14	21	17.5	35.6	58.3	47.0
Arequipa × Smooth Awn	(")	II-21-36	16	13	14.5	34.5	50.2	42.4
Bay Brewing			2	6	4.0	21.5	48.3	34.9
Lion			9	11	10.0	32.6	61.0	46.8
Bay Brewing × Lion		II-20-29	15	12	13.5	39.6	56.9	48.3
Sandrel	Culture 104		9	10	9.5	28.1	59.8	44.0
Smooth Awn	Culture 284		15	11	13.0	42.7	53.8	48.3
Sandrel × Smooth Awn	(C104 × C284)	II-21-30	19	15	17.0	35.7	61.9	48.8
Sandrel × Smooth Awn	(")	II-21-31	14	16	15.0	45.8	60.9	53.4
Sandrel × Smooth Awn	(")	II-21-32	19	16	17.5	33.0	61.6	47.3
Trebi		I-16-14	7	13	10.0	37.0	74.0	55.5
Smooth Awn	Culture 284		15	11	13.0	42.7	53.8	48.3
Trebi × Smooth Awn		II-21-33	19	17	18.0	32.5	59.4	46.0

* This smooth-awned hybrid has been compared with Manchuria, Minn. 184, in field plot trials which have been carried on at both the Central Station and the Substations. It has been approved for distribution under the name Velvet, Minn. No. 447.

Many of the crosses appear very promising and have given yields equal to the better Manchuria selections or superior.

A few of the crosses have not given any hybrids as resistant as the better Manchuria strains. These are worth noting. The crosses between Arequipa, Culture 267, and Smooth-Awn, Culture 284, gave a segregation for reaction to spot blotch disease, but none of the hybrids

Fig. 6. Relative Reaction of Two Smooth-awned Hybrids
At left, spikes of resistant, smooth-awned hybrid II-20-10; at right, spikes of susceptible smooth-awned hybrid II-21-36.

is as resistant as some strains obtained from other crosses. The Bay Brewing × Lion cross as well as those of Sandrel × Smooth Awn and Trebi × Smooth Awn are all somewhat susceptible. As would be expected, it is very difficult, if not impossible, to obtain resistance from a cross in which both parents are susceptible. This emphasizes the point, which is becoming generally recognized, that the greatest success can be expected from a well organized plant breeding mode of attack in which the parents are selected on the basis of certain desirable characters which they possess.

SUMMARY

1. *Helminthosporium sativum* Pammel, King and Bakke is the cause of a serious disease of barley. The disease appears in various ways and causes culm and foliage spots, foot- and root-rots, and seedling blight, and frequently prevents development of several seeds in each spike.

2. A study of varietal resistance was made by sowing each variety in a five-foot row and spraying the plants at heading time, at intervals of a day or two, with spore suspensions of the causal organism. Yield tests of the same varieties were made in a separate field in replicated rod rows.

3. The importance of the disease is apparent by the correlation between the degree of infection under epidemic conditions (the five-foot row trial) and the yield of the same varieties or strains in replicated rod-row trials. A correlation coefficient between yield and severity of infection for seventeen six-rowed strains was $+.575\pm.109$ and for the thirty-nine purified smooth-awned hybrids was $.445\pm.087$.

4. Varietal resistance was found to be of utmost importance. In general, varieties which were resistant one year tended to be resistant the following year, while varieties that were susceptible one year tended to be susceptible the following year. Resistance and susceptibility, however, are relative characters and the degree of infection is widely influenced by environmental conditions.

5. Barleys of the Manchuria type proved rather resistant, altho one strain of Manchuria appeared more susceptible each year of the trial than other strains. Mariout and Bay Brewing are extremely susceptible, while Trebi and Lion are rather susceptible. Within the hulled, six-rowed group, therefore, all degrees of resistance and susceptibility were obtained.

6. The new six-rowed variety, Minsturdi, which excels in strength of straw and has been recently introduced to Minnesota farmers, appears resistant.

7. In the naked-bearded, six-rowed group, Himalaya appeared susceptible while Black Hull-less and Nepal were resistant.

8. Nearly all of the more commonly grown two-rowed barleys proved resistant altho some of the two-rowed varieties that were tested proved susceptible.

9. Three varieties belonging to the *Hordeum intermedium* group appeared susceptible, while both resistant and susceptible varieties were grown which belonged to the *Hordeum deficiens* group.

10. Correlation coefficients were calculated which express the correlation of the severity of infection for the separate years of the trial.

Forty-nine varieties or strains were grown in both 1920 and 1921. The calculated coefficient of correlation for the degree of infection for these years was .497±.073. Sixty-seven varieties or strains grown in both 1921 and 1922 gave a coefficient of correlation of .616±.051 for degree of infection for the separate years.

11. Separate notes on the degree of infection of foliage, roots, and spikes were taken and correlation coefficients were calculated which expressed the extent to which infection in one part of a plant may be used to estimate the infection in another part of a plant of the same variety. The calculated coefficients ranged from .362±.073 to .464±.047 in 1921 while all three coefficients were between .7 and .8 in 1922.

12. Seedlings of 98 barley varieties were grown in the greenhouse in soil inoculated with cultures of *H. sativum,* and notes were taken on root infection. The correlation coefficients which express the relation between root infection in the greenhouse and infection in the field were between .3 and .4.

13. Thirty-nine smooth-awned hybrids which appeared homozygous were obtained for the most part from crosses between a smooth-awned susceptible variety and a rough-awned resistant variety. Both resistant and susceptible smooth-awned varieties were obtained.

14. Under the conditions which prevail at University Farm, resistance to *H. sativum* is a character which is of much importance to the plant breeder and the crop producer.

PART II. INHERITANCE STUDIES OF A CROSS BETWEEN LION AND MANCHURIA

Several years ago a cross[1] was made between Lion, a smooth-awned, black barley, and Manchuria, for the purpose of producing a smooth-awned variety of the Manchuria type. When the original cross was made it was not known that Lion was susceptible to *Helminthosporium sativum* P. K. and B. The first smooth-awned varieties produced from the Lion-Manchuria cross were found, after they had been tested for several years, to be susceptible to *H. sativum* and for this reason were discarded altho under some conditions (in the absence of severe *Helminthosporium* injury) these new varieties gave high yields. [See Harlan and Hayes (5), Hayes and Stakman (6)].

Further crosses were made and special attention was paid to *Helminthosporium* resistance as well as to plant type. Varieties are now available which appear as resistant as Manchuria and which in preliminary trials have given high yields. Because of the importance of the smooth-awn habit and of resistance to *H. sativum* it seemed desirable to make a careful study of the mode of inheritance of these characters in the Lion-Manchuria cross. The results will be presented in the following order: (1) Inheritance of awn habit and black vs. white color. (2) Inheritance of reaction to *H. sativum*. (3) Correlation between reaction to *H. sativum* and botanical characters.

INHERITANCE OF AWN HABIT AND BLACK VS. WHITE COLOR

Harlan (3) discussed the introduction of smooth-awned barleys into the United States and pointed out that all smooth-awned barleys are not equally smooth. The fact was emphasized that the teeth which occur on the upper part of the awn of smooth-awned barleys are not particularly objectionable, as the awns are so smooth that they can be pulled across the face in either direction without roughness being apparent except at the tip. By the time the barley spike is mature the tip of the awn frequently breaks off, so that the part on which teeth are borne may be lost before the crop is handled at threshing time.

Vavilov (11) has pointed out that smooth-awned barleys probably were originally obtained by hybridization. This conclusion was reached as a result of certain crosses between rough-awned varieties in which some smooth-awned plants were obtained in F_2. As a rule the progeny of smooth-awned plants bred true for the smooth-awned

[1] The crosses were made by the Office of Cereal Investigations, U. S. Dept. of Agr. Subsequent breeding studies have been carried on by the Minnesota Agricultural Experiment Station in co-operation with the Office of Cereal Investigations.

character. Smooth- and rough-awned barleys in some crosses apparently differed in several inherited factors for awn condition. These factors modified the character, form, and frequency of the teeth produced on rough-awned varieties.

The studies of inheritance reported here are from the F_2 to F_4 generations of crosses between a pure line of Lion, a black, six-rowed, smooth-awned barley; and a pure line of Manchuria, a white, six-rowed, rough-awned variety. From observations made on other smooth-awned strains it was apparent that there was a considerable range in degree of smoothness of the awns in the segregating generations. Accordingly, the F_2 generation of the Lion-Manchuria cross was classified into three groups, rough, intermediate smooth, and smooth.

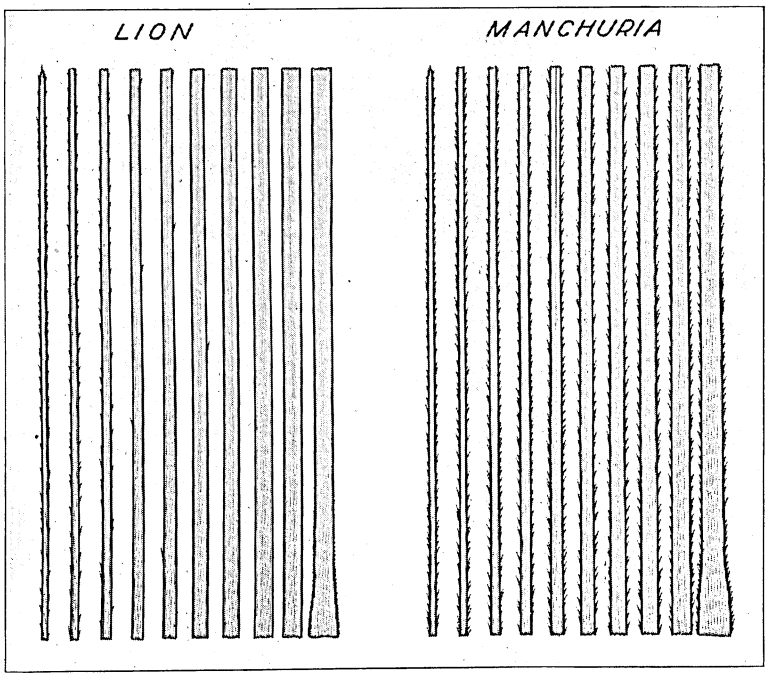

Fig. 7. Lengthwise Section of Average Awn of Lion and Manchuria Barleys Enlarged approximately eight times. (Drawing by George)

The rough group, similar to Manchuria, produced teeth on the entire length of the awn. All smooth-awned barleys that have been grown at the Minnesota Experiment Station have some teeth on the tip of the awn and also have teeth at the extreme lower base of the awn, altho in the smooth-awned barleys there are teeth on the base for only a short distance. A comparison of the relative size and number of teeth on Lion and Manchuria barleys may be seen in Figure 7.

In discussing the relative smoothness of the awns of various smooth-awned hybrids the teeth at the awn base will be disregarded.

The intermediate group produced teeth on approximately the upper half of the awn altho there was some part of the lower half of the awn upon which no teeth were apparent; while the smooth group produced teeth on approximately the upper third of the awn only.

The F_2 generation grown in 1918 from nine separate F_1 plants is classified in Table XII for color of spike and condition of awn. Of 315 plants, 225 were rough-awned and 90 were smooth-awned. The deviation from expectation on the basis of a single main factor difference between rough and smooth is 11.25, while the probable error on the basis of 315 individuals is 5.18.[2] A deviation as great as this might be expected to occur about once in every 7.28 trials. There were 225 black and 90 white, the same ratio as was obtained for rough vs. smooth awns.

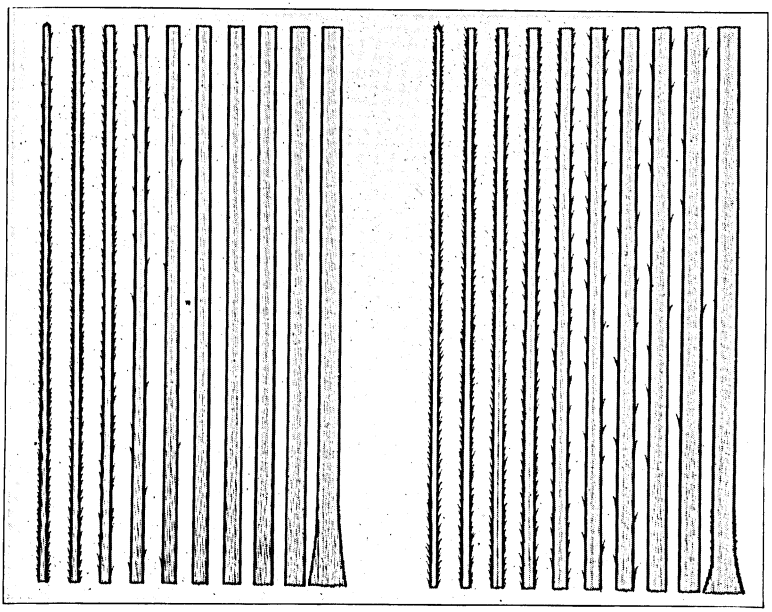

Fig. 8. Lengthwise Section of Average Awn of Two Families of Lion×Manchuria Barley At left, average awn of a plant of the smooth-awned hybrid family, Culture No. 205; at right, average awn of a plant of the intermediate smooth-awned hybrid family, Culture No. 266. Enlarged approximately eight times. (Drawing by George.)

[2] Probable errors of Mendelian ratios were obtained from tables of probable errors from the Department of Plant Breeding, Cornell University.

TABLE XII

F_2 GENERATION OF LION × MANCHURIA CLASSIFIED FOR COLOR AND CONDITION OF AWN

F_2 plant No.	"Rough"		"Interm. smooth" Sl. rough		"Smooth" V. Sl. rough	
	Black	White	Black	White	Black	White
52	25	9	5	2	2	1
54	9	8	8	1	4	1
49	13	9	4	3	3	1
50	19	3	12	1	5	1
51	19	10	2	4	1	1
53	17	5	3	5	2	0
56A	26	9	1	0	2	2
56	11	6	3	2	2	0
55	22	5	2	0	3	1
Total	161	64	40	18	24	8
	225		58		32	

There was no apparent linkage in inheritance of the allelomorphic pairs for rough vs. smooth awn and black vs. white color, as may be noted by an examination of the results obtained in F_2.

	Black rough	Black smooth	White rough	White smooth	Total
Observed	161	64	64	26	315
Calculated	177	59	59	20	315
Difference	16	5	5	6	0
	$X^2 = 4.08$		$P = .2543$		

Further proof that black and white are dependent for their expression upon a main factor difference was obtained from the F_3 generation. Of a total of 62 F_3 families planted from black F_2 plants selected at random, 18 were homozygous for black an 44 produced both black and white plants.

In order to make a more exact study of the mode of inheritance of the smooth vs. rough awn habit, the various plants were classified by determining what part of the total length of the awn produced teeth rather regularly.

An awn of average length was taken from the center of the main spike of each plant and was carefully examined under the binocular. The distance on the tip of the awn upon which teeth were regularly borne was measured. The total length of the awn was divided by the length of the tip upon which teeth were found. The result obtained was called the awn index; the larger the index the smoother the awn, and vice versa.

Plants of the Lion parent with different indices were selected and the progeny were compared for awn index value. (See Table XIII.)

TABLE XIII

INHERITANCE STUDIES OF AWN INDEX VALUES WITH THE LION PARENT

Index of parent plant	Year grown	Awn index classes, progeny										
		2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.5
	1921	1	14	21	21	18	4	4	1	1		
3.1	1922		4	2	1	1						
3.0	"	1	2	6	3	1						
4.0	"	1		4	1		1				1	
2.5	"	1		2	1	2	1					
3.4	"	1	2	5	3	2	1					
3.3	"		4	6	2	1						
3.4	"	1	5	2	2							
4.0	"	1		8	3	1	1					
3.1	"	1	1	2	2		1	1				1
3.0	"	3	3	1	2	2						
2.7	"	1	2	1			1					
3.2	"			2	1	1						
2.8	"	2	3	4	2	2	1					
2.8	"	3	2	3	1	2		1	1			
2.7	"	1	2	2	2	4						
Total	1922	17	30	50	26	19	7	2	1	0	1	1

The results obtained for the Lion parent indicate a considerable range of variability for the awn index. There is, however, little indication that the variations are heritable, for little or no relation is apparent between the index of the parent plants and the index of the progeny. Such fluctuations as appear on individual plants of the Lion parent are apparently not heritable.

A careful examination was made in 1921 of the spikes of nearly three hundred F_2 plants of the Lion-Manchuria cross for degree of smoothness of awn. The results are compared with the parents, Manchuria and Lion, and are also compared with various F_3 families which were grown the same season from F_2 plants whose awn indices were known. This material was likewise tested for reaction to *H. sativum*. A summary of the results for awn indices is given in Table XIV.

There were 203 rough-awned F_2 plants and 85 smooth-awned plants of various degrees of smoothness. Of these, 39 had teeth for a greater distance on the awn than is usual on the Lion parent. On the basis that there is a single main factor difference between rough and smooth awn, the expected ratio for 288 plants would be 216:72. The deviation from expectation is 13 and the probable error in numbers for 288 plants on a 3:1 basis is 4.96. The deviation divided by the probable error is 2.6. A deviation as great as this might be expected to occur once in every 12.58 trials.

TABLE XIV

INHERITANCE OF SMOOTH VERSUS ROUGH AWN HABIT IN F_2 AND F_3 OF THE CROSS BETWEEN LION AND MANCHURIA

Variety	Culture No.	Awn index of parent plant	No. of families	Awn index classes of progeny							
				1.0	1.3	1.9	2.8	3.7	4.6	5.5	6.4
Manchuria			6	66							
Lion			6				97	62	3	2	
Man. × Lion F_2			7	23	1	38	39	7			
Man. × Lion F_3	166	2.5			1	15					
"	170	2.1			1	10					
"	182	1.8				16					
"	252	1.6				16					
"	266	1.0			3	8					
Total			5		5	65					
Man. × Lion F_3	171	1.8				10	6				
"	174	2.2				9	9				
"	175	2.0				3	1				
"	172	2.1				11	2				
"	207	1.9			1	12	2				
"	216	2.2			1	12	1				
"	236	2.3				8	12				
"	237	2.3				10	7				
"	238	1.8				18	6				
"	240	2.1				7	7				
"	181	2.1				10	5				
"	217	2.0				14	6				
"	271	2.0				6	14				
Total			13		2	130	78				
Man. × Lion F_3	169	2.0				7	5	2			
"	173	2.1				9	3	1			
"	176	2.2				9	4	1			
"	177	2.2				3	2	5	1		
"	215	2.2				5	9	1			
"	218	1.8				3	4	6	2		
"	249	1.8			1	7	2	2	1		
"	253	1.6			2	2	2	2			
"	270	2.0			1	10	1	2	1		
"	272	1.9				9	9	4			
"	273	2.1				5	5	2			
"	282	1.8				8	6	1			
Total			12		4	77	52	29	5		
Man. × Lion F_3	206	2.2						13	2	1	1
"	208	2.4					3	5	6	1	
Total			2				3	18	8	2	1
Man. × Lion F_3	165	3.3					7	8			
"	205	3.8						9	8	4	
"	239	3.4					2	6	5	2	
"	248	2.6					2	5	2		
"	281	2.8					4	4	2		
Total			5				15	32	17	6	

TABLE XIV—*Concluded*

INHERITANCE OF SMOOTH VERSUS ROUGH AWN HABIT IN F_2 AND F_3 OF THE CROSS BETWEEN LION AND MANCHURIA

Variety	Culture No.	Awn index of parent plant	No. of families	Awn index classes of progeny							
				1.0	1.3	1.9	2.8	3.7	4.6	5.5	6.4
Man. × Lion F_3	250	2.7				7	5	2	2		
"	280	2.9				1	8	9	1	1	
Total			2			8	13	11	3	1	
Man. × Lion F_3	Total	1.0	21	338							
"	185	1.0		13		2	1				
"	187	1.0		11		4	5				
"	192	1.0		2		3					
"	194	1.0		19		1	3				
"	197	1.0		7		2					
"	198	1 0		8		1					
"	220	1.0		16		1	1				
"	227	1.0		9		1	1				
"	228	1 0		14		2	1				
"	231	1.0		12		2	2				
"	232	1.0		15			3				
"	241	1.0		14		4	1				
"	244	1.0		21		3	1				
"	247	1.0		11		3					
"	254	1.0		4		1					
"	258	1.0		14		7	1				
"	260	1.0		12		1					
"	261	1.0		12		1	1				
"	262	1.0		7		4	1				
Total			19	221		43	22				
Man. × Lion F_3	219	1.0		12		2	2	2			
"	224	1.0		13		1		1			
"	234	1.0		9		1	5	1			
"	235	1.0		15		2	3	1			
"	245	1.0		17		2	2	1			
"	246	1 0		5		1		1			
"	255	1.0		11		3	3	2			
"	257	1.0		9		2	2	2			
Total			8	91		14	17	11			
Man. × Lion F_3	191	1.0		16			2	2			
"	193	1.0		14				3	2		
"	202	1.0		9			5	1			
"	213	1.0		5			3				
"	214	1.0		12			2	2	1		
"	223	1.0		13				1			
"	225	1.0		11			2	2			
"	229	1.0		16				1	1		
"	259	1.0		13			2	4	2		
"	265	1.0		19				1	2		
"	268	1 0		10			4	3	3		1
"	277	1.0		13			3	4			
"	278	1.0		9			3	3			
Total			13	160			26	27	11		1

A total of 63 F_3 lines from rough-awned F_2 plants was grown. Of this number, 21 bred true for the rough-awn habit while 42 gave both rough- and smooth-awned plants. These results give further proof that a single main factor differentiates rough- and smooth-awned types. The F_3 families which produced both rough- and smooth-awned plants were placed in three different groups on the basis of the degree of smoothness of the smooth-awned segregates. In one group of 19 families the awn index of the smooth-awned plants was low. In another group of 13 families the smooth-awned plants were all of an awn index similar to that of the smooth-awned parent, Lion; while the third group contained smooth-awned plants of both a high and a low awn index. The numbers of individuals were small in these F_3 lines. The F_3 families which produced both grades of smooth-awned individuals are without doubt genotypically of the nature indicated. The number of individuals in the F_3 families in which rough-awned plants and smooth-awned plants obtained were in either the low index group or in the high index group, was too small to prove conclusively that the particular family was genotypically capable of producing only one class of smooth-awned plants.

In the 63 families which segregated giving both smooth-awned and rough-awned plants, there were 644 plants, of which 172 were smooth-awned. On a 3:1 basis, 161 smooth-awned plants should be expected. The deviation from expectation is 11 and the probable error for a 3:1 ratio on the basis of 644 individuals is 7.41.

All smooth-awned F_2 plants bred true for the smooth-awned condition in F_3. The F_3 families were, however, of different apparent type, for some produced only plants of low-awn indices, others produced only plants of high-awn indices, while still others produced some smooth-awned plants of both low- and high-awn indices.

Several lines from different F_3 types were tested by growing F_4 progeny. (See Table XV.)

From the F_3 group with the lowest average index, two lines were selected, Nos. 166 and 266. Both bred comparatively true to the low index habit in F_4, altho family 266 produced a somewhat lower average index than family 166.

From the near intermediate smooth group 6 lines were tested in F_4. Of these, 2 gave rather clear indication of segregation while 4 bred comparatively true. Of the 5 segregating lines, 4 gave evidence in F_4 that showed that these 4 lines were not homozygous. From the fifth line, F_3 plants with a high awn index only were selected for planting in F_4. The two lines tested bred true for the high index character. The 4 F_3 families with as high average index as Lion, bred true for a high index in F_4.

TABLE XV

F_4 Breeding Behavior in Relation to F_3 Group for Awn Index

Parent plant	Awn index of parent plant	Group of parent plant	Gen.	Awn index classes of progeny						
				1.3	1.9	2.8	3.7	4.6	5.5	6.4
166	2.5	Int. smooth	3		15					
166-3	2.0		4	1	10	5				
166-4	2.0		4		5	2				
166-13	1.7		4		14	2				
266	1.0	Int. smooth	3	3	8					
266-9	1.6		4	3	16					
266-12	1.8		4	1	8					
266-5	1.6		4	1	7					
174		Near Int. smooth	3		9	9				
174-6	2.6		4		1	7	1			
174-10	2.0		4			5				
181	2.1	Near Int. smooth	3		10	5				
181-14	2.3		4	3	12					
181-3	2.0		4		4	5				
181-10	2.1		4	2	18					
207	1.9	Near Int. smooth	3	1	12	2				
207-12	2.6		4	1	11					
207-14	1.5		4	1	19					
207-3	1.5		4	3	19					
271	2.0	Near Int. smooth	3		6	14				
271-12			4		1	5	5	1		
271-5			4		2	9	3	3		
236	2.3	Near Int. smooth	3		8	12				
236-1	2.0		4		16	6	1			
236-11	2.9		4		20	1				
237	2.3	Near Int. smooth	3		10	7				
237-2	3.1		4		2	6	3	1		
237-5	2.5		4		13	8	1			
177	2.2	Segregating	3		3	2	5	1		
177-1	4.5		4			2	2			
177-4	2.3		4	1	5	2				
218	1.8	Segregating	3		3	4	6	2		
218-2	3.3		4		15	4	1			
218-3	2.8		4		3	5	12	4		1
218-4	3.8		4			1	7	10		2
218-5	4.1		4			13	6	1	4	
218-12	4.0		4		9	8	4			
218-15	3.4		4		2	12	5	1		
249	1.8	Segregating	3	1	7	2	2	1		
249-3	1.4		4		10	3	2			
249-7	1.8		4	1	15					
249-10	4.2		4			3	12			
253	1.6	Segregating	3	2	2	2	2			
253-1	3.7		4			9	6	3		
253-3	1.4		4		4	1				
253-7	2.3		4		17	2				

TABLE XV—*Concluded*

F_4 BREEDING BEHAVIOR IN RELATION TO F_3 GROUP FOR AWN INDEX

Parent plant	Awn index of parent plant	Group of parent plant	Gen.	Awn index classes of progeny						
				1.3	1.9	2.8	3.7	4.6	5.5	6.4
250	2.7	Segregating	3		7	5	2	1		
250-1	3.3		4				5	2	4	4
250-17	3.8		4			1	7	8		4
206	2.2	Smooth	3				13	2	1	1
206-6	4.1		4			6	4	3	3	3
205	3.8	Smooth	3				9	8	4	
205-2	4.0		4			1	11	1		
205-3	4.0		4			4	11	4	1	
205-13	4.1		4			2	7	4	2	2
248	2.6	Smooth	3			2	5	2		
248-5	3.2		4			3	5	5	2	
248-6	4.0		4				9	1		
248-4	2.8		4			3	5			
239	3.4	Smooth	3			2	6	5	2	
239-8			4			2	5	1	1	1
239-9			4				3	2		
239-15			4			2	6	5	5	2
239-2	4.4		4			5	16	1	1	
239-12	3.3		4			2	9	7	1	
239-13	4.7		4			5	13	3	1	1
239-16	4.6		4			6	11	5	1	
239-17	3.2		4			5	9	5	2	

These results prove that the degree of smoothness of the awn is an inherited character and apparently dependent on genetic factors. The simplest explanation is that there is one main factor which differentiates smooth- and rough-awned types and that modifying factors determine the degree of smoothness of the awns of the smooth-awned plants. This seems a better explanation than the view of a variable factor, for types breed true in F_3 and F_4 for different degrees of smoothness.

INHERITANCE OF REACTION TO H. SATIVUM

The F_3 and F_4 families, of which from 10 to 25 plants each were grown, were inoculated about heading time by spraying with a spore suspension of *Helminthosporium sativum*. About harvest time a separate note was taken on each plant on the degree of infection of spike, culm and leaves together, and root. The notes were taken as heavy, medium, light, and trace, plus and minus signs being used to denote deviation from the class centers. In order to average the results the following numerical figures were used:

trace = 10	medium — = 6	heavy — = 3
light — = 9	medium = 5	heavy = 2
light = 8	medium + = 4	heavy + = 1
light + = 7		

By averaging the results for the three groups a numerical index of degree of infection was obtained. The least infection obtainable was represented by trace, or 30, while the heaviest obtainable infection would be heavy + or 3, i.e., heavy + on spike, culm and leaves, and root.

At frequent intervals, approximately every tenth to twentieth row, the parents were planted.

The difficulty of a study of this kind is that environmental conditions so widely influence the degree of infection. In a single resistant variety, such as Manchuria, plants may be found which are very heavily infected, altho the other plants in the population may escape serious injury. Similarly, a susceptible variety, such as Lion, may produce an occasional plant which is only moderately infected. These facts may be illustrated by the variations obtained in 1921 from the parental rows.

TABLE XVI

VARIATION IN INFECTION OF ROWS OF PURE LINES OF MANCHURIA AND LION BARLEYS

Variety	Row No.	Range of infection numerically expressed	Mean infection
Lion	167	6 – 8	6.9
Manchuria	168	12 – 22	17.0
Lion	178	6 – 13	11.1
Manchuria	179	14 – 18	15.7
Lion	189	7 – 15	11.5
Manchuria	190	12 – 23	18.2
Lion	200	6 – 13	9.6
Manchuria	201	8 – 16	13.1
Lion	221	7 – 14	11.2
Manchuria	222	9 – 20	15.3
Lion	242	11 – 17	14.2
Manchuria	243	11 – 23	17.9
Lion	263	10 – 15	12.3
Manchuria	264	10 – 18	14.1
Lion	284	9 – 17	13.3
Manchuria	285	10 – 23	17.4
Lion	305	5 – 12	8.3
Manchuria	306	6 – 26	16.8

In order to discover whether the difference in reaction of individual plants with a pure line such as Lion or Manchuria was heritable, several plants of both a high and a low infection were selected and their progeny grown the following year. Within each pure line the progeny from the plants which were severely infected in 1921 were no more severely injured in 1922 than the progeny from the plants which in 1921 were only slightly injured. The following will serve as typical illustrations:

Variety	Parent plant	Average infection of parent plant	Average infection of progeny
Manchuria	168–11	14	26.5
Manchuria	168–7	22	23.8
Manchuria	179–7	14	27.8
Manchuria	179–5	18	26.5
Manchuria	264–10	11	24.8
Manchuria	264–9	18	25.3
Lion	189–1	7	19.2
Lion	189–15	16	18.4
Lion	200–4	7	15.6
Lion	200–1	13	13.5
Lion	263–4	10	13.1
Lion	263–12	14	13.4

The variability which was obtained from the various cultures of the parents may be noted from the data given in Table XVII. In 1921 the barley plots were planted much later than in 1922. Both varieties were much more severely infected in 1921 than in 1922. In fact the resistant variety, Manchuria, was nearly as severely infected in 1921 as the susceptible variety, Lion, was in 1922. There was, however, a very significant difference in both years between the average infection of the two varieties.

The standard deviations for the susceptible variety, Lion, were larger in both years than for Manchuria, altho the differences are not statistically very significant.

The probable error of a single determination, i.e., the use of a single row for Lion, in 1922, would be $2.46 \times .6745$, or 1.66. This shows that rather large deviations may be expected.

The means of 124 F_3 lines of the Manchuria-Lion cross are given also in Table XVII. While the means cover as wide a range of variability as the combined range of Lion and Manchuria, the calculated standard deviation is only $.86 \pm .40$ greater than for Lion, which is not statistically very significant.

As has been mentioned, Lion and Manchuria were grown every tenth to twentieth row. After comparing the means obtained for the parent lines with those obtained for the hybrids, certain hybrid families were selected which appeared to be either as susceptible as Lion or as resistant as Manchuria. Within each apparently susceptible F_3 line two of the most resistant plants and one susceptible plant were selected, and within each apparently resistant family two of the most susceptible plants and one resistant plant were selected. An F_4 culture was grown in 1923 from each of these selected plants.

Average results are given in Table XVIII for the various rows of the parents and crosses.

Fig. 9. Reaction of Manchuria and Lion to *H. sativum*.
At left, culms of Manchuria; at right, culms of Lion.

TABLE XVII

AVERAGE REACTION OF VARIOUS CULTURES OF MANCHURIA, LION, AND F_3 LINES OF THE MANCHURIA-LION CROSS TO *H. sativum*

Variety	Year	Average numerical figure									No. of Cult.	Mean	S. D.
		6	9	12	15	18	21	24	27	30			
Manchuria	1921			1	3	5					9	16.3±.46	2.06±.33
Manchuria	1922							8	5	1	14	25.5±.34	1.88±.24
Lion	1921	1	2	5	1						9	11.7±.55	2.43±.39
Lion	1922			2	6	4	1				13	15.9±.46	2.46±.33
Manchuria × Lion F_3	1921		13	36	60	13	2				124	14.3±.20	3.29±.14

In 1921 only a single row of each culture was grown, while in 1922 each parent check culture was represented by two rows, while each hybrid culture consisted of 3 rows. Each row of each hybrid line was the progeny from an individually selected plant whose reaction was known. The reactions in 1922 for each line are given in the same order in the table as the reaction for the parent plants. Thus three plants of the line 173, with reaction indices of 6, 11, and 13, were selected in 1921. The progeny of these three plants gave mean reactions of 13.5, 12.7, and 20.7, respectively. There is some evidence in this line of a heterozygous condition. Line 203, however, in which

Fig. 10. Reaction of Manchuria and Lion to *H. sativum*
At left, spikes of Manchuria; at right, spikes of Lion.

individual plants with reactions of 11, 12, and 20 were selected, produced progeny with average reactions of 24.6, 22.0, and 23.6. The evidence obtained indicates that the line 203 is homozygous and resistant. A careful examination of the results leads one to conclude that some of the hybrid lines are resistant like Manchuria while others

TABLE XVIII

REACTION TO *H. sativum* OF MANCHURIA, LION, AND F_3 LINES OF THE MANCHURIA-LION CROSS

Variety	Reaction 1921	Mean reaction 1922				Average 1922	Average 1921, 1922	Reaction, parent plants		
Lion	6.9	14.7	15.5	....		15.1	11.0	8	6	..
Manchuria	17.0	26.5	23.8	....		25.2	21.2	14	22	..
166	9.1	24.4	19.6	22.3		22.1	15.6	6	12	14
173	8.4	13.5	12.7	20.7		15.6	12.0	6	11	13
174	7.6	13.8	12.4	....		13.1	10.4	6	10	..
177	9.2	13.9	12.0	11.4		12.4	10.8	6	12	14
181	15.8	18.2	21.5	....		19.9	17.9	12	23	..
185	16.7	22.2	25.0	25.7		24.3	20.5	7	15	23
203	16.6	24.6	22.0	23.6		23.4	20.0	11	12	21
204	15.2	23.7	24.8	23.6		24.0	19.6	11	12	20
Lion	11.1	19.5	....	....		19.5	15.3	13	..	..
Manchuria	15.7	27.8	26.5	....		27.2	21.5	14	18	..
193	10.0	26.4	26.2	....		26.3	18.2	7	15	..
202	7.6	16.9	20.6	19.7		19.1	18.4	7	9	10
229	12.3	18.4	18.7	19.1		18.7	15.5	7	15	16
230	9.5	22.6	22.4	18.2		23.1	16.3	7	14	14
Lion	11.5	19.2	18.4	....		18.8	15.2	7	16	..
Manchuria	18.2	28.9	28.4	....		28.7	23.5	12	22	..
207	15.3	24.2	25.2	....		24.5	19.4	11	12	..
218	16.0	22.4	18.1	23.3		21.3	18.7	11	12	20
219	15.7	22.3	19.2	26.4		22.6	19.2	11	11	21
224	16.1	20.7	25.1	25.6		23.8	20.0	11	13	21
Lion	9.6	13.5	15.5	....		14.5	12.1	7	13	..
Manchuria	13.1	25.4	24.3	....		24.9	18.5	8	16	..
247	14.0	15.0	18.5	18.0		17.2	15.6	11	16	16
248	10.3	16.6	15.3	16.1		16.0	13.2	6	13	13
249	11.4	21.7	24.9	25.0		24.0	17.7	10	15	16
253	10.6	18.8	16.8	19.4		18.3	14.5	7	13	14
Lion	11.2	19.2	18.7	....		19.0	15.1	..	..	..
Manchuria	15.3	26.8	....	....		26.8	21.1	..	..	..
228	15.2	21.5	26.9	28.0		25.5	20.4	12	12	20
235	17.0	19.4	23.9	18.0		20.4	18.7	11	13	22
239	16.4	16.0	15.2	....		15.6	16.0	13	18	..
241	18.7	20.7	17.8	21.7		20.1	19.4	15	15	21
Lion	14.2	16.7	14.7	....		15.7	15.0	11	17	..
Manchuria	17.9	25.2	....	....		25.2	21.6	21	..	..
257	11.9	19.2	17.3	25.6		20.7	16.3	7	17	17
258	12.8	18.8	20.1	16.6		18.5	15.7	6	17	17
259	12.9	13 3	15.0	16.3		14.9	13.9	8	16	19
274	11.8	19.8	22.2	....		21.0	16.4	15	18	
Lion	12.3	9.0	13.8	....		7.6	10.0	4	17	..
Manchuria	14.1	23.8	23.8	....		23.8	19.0	10	18	..
250	15.0	18.7	14.7	18.9		17.4	16.2	13	13	20
260	15.4	19.7	20.2	....		20.0	17.7	9	18	..
262	19.0	18.2	21.9	17.7		19.3	19 2	15	16	22
265	16.9	18.0	18.2	17.0		17.7	17.3	13	14	21
266	22.0	20 0	17.6	17.7		18.4	20.2	19	20	25
267	19 5	17.3	21.8	23.8		21.0	20.3	12	16	24
271	11.8	13.5	16.7	....		15.1	13.5	15	18	..
283	17.5	18.5	19.7	13.5		17.2	17.4	12	14	21
Lion	12.3	13.4	13.1	....		13.3	12.8	10	14	..
Manchuria	14 1	24.8	25.3	....		25.1	19.6	11	18	..

are as susceptible as Lion. Sixteen of the 36 families were selected in F_3 because they appeared as susceptible as the Lion parent. The following, on the basis of combined results for the two years, appear as susceptible as Lion: Lines 174, 177, 229, 230, 248, 253, 259, and 271, and were presumably homozygous in F_3 for susceptibility. The lines which appear resistant on the basis of the two years' study are as follows: Lines 185, 203, 204, and possibly 219, 224, and 228. Line 193, which was apparently susceptible in F_3, appeared highly resistant in F_4, while Line 239, which appeared resistant in F_3, appeared susceptible in F_4.

A correlation coefficient was calculated to determine the degree of correlation obtained from the F_3 result as determined from a single-row trial, and the result as obtained from an average of 3 rows for the various progeny lines in F_4.

TABLE XIX

CORRELATION BETWEEN REACTION TO *Helminthosporium sativum* IN F_3 LINES AND F_4 LINES

Average reaction, 1922	Reaction, 1921: 9	12	15	18	21	
12	2					2
15	2	2	1			5
18	1	3	2	3	1	10
21	1	2	3	2	1	9
24	1	1	4	2		8
27	1		1			2
	8	8	11	7	2	36

$r = .256 \pm .105$

The calculated coefficient of correlation, $+.256 \pm .105$, is about two and a half times its probable error. It seems reasonable to conclude that by the use of several rows of a line systematically distributed over the field, a fairly reliable criterion of resistance and susceptibility could be obtained.

The evidence presented would indicate that from 124 F_3 lines which were grown in F_3, 8 were homozygous for susceptibility and 6 for resistance. Results of this nature could be explained on the hypothesis that Lion and Manchuria differed by two main factors for resistance and susceptibility to *H. sativum*. The presence of both factors might be considered to lead to the production of resistance while the absence of both might be supposed to produce a susceptible type.

Seed from the various plants of a family of 70 of the F_4 lines grown in the field in 1922, was mixed together and planted in the

greenhouse in infected soil from the field plot and in sterilized soil inoculated with a culture of *H. sativum.* From the study of various barley varieties, the conclusion was reached that root infection under greenhouse conditions was the best criterion of resistance and susceptibility under field conditions.

A correlation coefficient was calculated to show the degree of correlation in infection under field conditions and the root infection under greenhouse conditions. The correlation coefficient obtained was $+.118\pm.079$. From an examination of Table XX it may be noted that several lines which were apparently highly resistant under field test were susceptible under the greenhouse test. The correlation coefficient is so small in relation to its probable error that it is not significant.

TABLE XX

CORRELATION BETWEEN THE REACTION TO *H. sativum* UNDER FIELD CONDITIONS OF F_4 LINES OF THE CROSS BETWEEN LION AND MANCHURIA WITH THE AVERAGE ROOT INFECTION OF THEIR F_5 PROGENY UNDER GREENHOUSE TEST

Average root infection, greenhouse, 1922-23	Average reaction under field conditions, 1922																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
4.5											1						L	
5.0							1	1	1		1				1		4	
5.5	1					1				1			1	1	1		6	
6.0			2	1	2		2								1		8	
6.5			1	2	1	1	2	2			1		1		1		12	
7.0					1	2	1	2		3	5		1		1		16	
7.5				1				1	3		2		1		1		9	
8.0						1	1		2				1	1			6	
8.5		1						3							1	1	6	
9.0														1			1	
	1	1	3	4	4	5	7	9	6	4	10	0	5	3	7	1	70	

$r = +.118\pm.079$

The apparent lack of correlation between field and greenhouse trials might, however, be a result of the inaccuracy of the test rather than a real lack of relation. To further test this point, the thirty-six F_3 families which were selected as possibly homozygous for resistance and susceptibility were used. The average reaction to *H. sativum* in the field in 1921 and 1922 was computed for these 36 families. It will be recalled that only a single row of each was grown in 1921 and that 3 plants were selected in 1921 from each of the 36 families to test in 1922. The average field result for 1921-22 is then based on four rows, one of which was grown in 1921 and the other three in 1922. All three rows of each line were, however, grown side by side in 1922.

The greenhouse work consisted of a test of two of each of the three lines of each of the 36 families except in two cases where only one line was available. The results from these two lines were averaged, each line being tested in sterilized soil which was inoculated with *H. sativum* and in infected soil from the field plot.

A correlation coefficient of $+.426\pm.092$ was obtained. This expresses the degree of correlation for the average field reaction in 1921 and 1922 to *H. sativum* of 36 F_3 Manchuria-Lion crosses with the root infection obtained in the greenhouse. This coefficient gives further evidence to prove that resistance and susceptibility to *H. sativum* are inherited characters. The correlation is very much larger than that obtained from the use of a single field row and a single greenhouse test. It gives furher evidence to show that in studying the mode of reaction to *H. sativum* it is essential to use several plots in order to obtain a reliable result. Replication would certainly be of value in a study of this nature.

TABLE XXI

CORRELATION BETWEEN AVERAGE REACTION TO *H. sativum* IN THE FIELD UNDER F_3 AND F_4 TEST OF 36 F_3 LINES OF THE CROSS LION × MANCHURIA WHICH WERE SELECTED IN F_3 EITHER AS RESISTANT AS MANCHURIA OR AS SUSCEPTIBLE AS LION WITH THE AVERAGE REACTION AS DETERMINED BY THE ROOT INFECTION UNDER GREENHOUSE CONDITIONS

Average reaction on roots in greenhouse	Average reaction in field, 1921-22												
	10	11	12	13	14	15	16	17	18	19	20	21	
5.0	1				1		1						3
5.5									1	1			2
6.0		1		1		1	1		1	2			7
6.5					1		3	1	1	1		1	8
7.0							3	1			3		7
7.5			1				1		2	1	1		6
8.0										1	1		2
8.5											1		2
	1	1	1	1	2	1	9	2	5	6	6	1	36

$r = +.426\pm.092$

CORRELATION BETWEEN REACTION TO H. SATIVUM AND BOTANICAL CHARACTERS

Because of the difficulty of determining the exact genetic nature of a particular F_3 family in relation to resistance and susceptibility, it seems unwise to make an extended analysis of the possible correlation between the genetic nature as to resistance and susceptibility and the genetic condition for botanical characters. Perhaps some idea of

the possibilities may be reached by a consideration of the families which appeared to be either resistant or susceptible as determined by the F_3 and F_4 studies. The facts are presented in Table XXI.

Of the susceptible families, 2 were homozygous for black color; one was homozygous for white; 5 were heterozygous for black vs. white; 4 were smooth-awned, 3 of which were heterozygous for degree of smoothness of the awn; and one was smooth-awned. Of the black homozygous families both segregated for degree of smoothness of awn.

TABLE XXI

BOTANICAL CHARACTERS OF THE FAMILIES OF THE LION-MANCHURIA CROSS WHICH APPEARED TO BE EITHER HOMOZYGOUS FOR RESISTANCE OR SUSCEPTIBILITY TO *H. sativum* AS DETERMINED BY F_3 AND F_4 TESTS

Line No.	Homozygous for	Botanical description
174	Susceptibility	Black, segregating for degree of smoothness of awn.
177	Susceptibility	Black, segregating for degree of smoothness of awn.
229	Susceptibility	Heterozygous for black vs. white, heterozygous for rough vs. smooth awn.
230	Susceptibility	Heterozygous for black vs. white, homozygous for rough awn.
248	Susceptibility	Heterozygous for black vs. white, homozygous for smooth awn.
253	Susceptibility	Homozygous for white, heterozygous for degree of smoothness of awn.
259	Susceptibility	Heterozygous for black vs. white, heterozygous for rough vs. smooth awn.
271	Susceptibility	Heterozygous for black vs white, heterozygous for degree of smoothness of awn.
193	Resistance	Heterozygous for black vs. white, heterozygous for rough vs. smooth awn. Both rough- and smooth-awned families were obtained in F_4.
203	Resistance	Homozygous for white color and rough awn.
204	Resistance	Homozygous for white color and rough awn.
219	Resistance	Homozygous for white color, heterozygous for rough vs. smooth awn. Homozygous intermediate smooth and homozygous smooth-awned families were obtained in F_4.
224	Resistance	Homozygous for white color, heterozygous for rough vs. smooth awn. A smooth-awned family which segregated for degree of smoothness of awn was obtained in F_4.
228	Resistance	Heterozygous for black vs. white, heterozygous for degree of smoothness of awn. An intermediate smooth-awned family was obtained in F_4.

Of the resistant families, 2 were homozygous for both white color and rough awn like the resistant Manchuria parent. Two others were homozygous for white color and segregated for rough vs. smooth awn.

From these families smooth-awned lines were obtained in F_4. Two other families were heterozygous for black vs. white, one of which segregated for rough vs. smooth awn, and the other produced all smooth-awned plants, altho there was considerable variation in the smoothness of the awn.

These facts show, as far as they go, that there is a tendency for a greater proportion of the resistant families to be of white color and rough awn than in the susceptible group. They likewise prove that if there is a linkage between resistance and susceptibility and botanical characters the linkage is not very close, for out of 124 F_3 lines all possible combinations of resistance and susceptibility with various types of characters were obtained.

The greenhouse reactions of the families 174 ,177, 229, 230, 248, 253, 259, and 271, which were apparently homozygous for susceptibility, were as follows: 5.25, 6.00, 7.50, 6.25, 6.25, 6.00, 6.75, and 5.00. All were susceptible in the greenhouse test except family 229. The greenhouse reactions of the families 193, 203 ,204 ,219, 224, and 228, were 5.5, 7.25, 8.5, 8.0, 7.0, and 7.75. All appear resistant except family 193. The greenhouse reactions of Lion were 7, 6, 6, 6, 7, 7, and of Manchuria 8, 8, 7.5, 8, 6.5, 7.5, 8. The susceptible hybrids were apparently more susceptible under greenhouse conditions than Lion. It has been noted previously that Lion is less severely infected under greenhouse conditions than many varieties belonging to the susceptible group.

As the data on the hybrid lines were taken without a knowledge of the previous year's results, it seems apparent that a test of infection under greenhouse conditions might be of some value as a means of isolating resistant families and of discarding susceptible ones.

SUMMARY

1. Crosses between Lion, a six-rowed, black, smooth-awned variety, which is susceptible to attacks of *H. sativum;* and Manchuria, a six-rowed, white, rough-awned, resistant variety, have been used to determine the mode of inheritance of the differential characters, rough vs. smooth awn, black vs. white color, and susceptibility vs. resistance.

2. The rough-awned character proved dominant to smooth awns and in F_2 the ratio of rough- to smooth-awned plants approximated 3:1. There were different degrees of smoothness of awn, some plants producing small teeth on approximately the upper third of the awn only, while other smooth-awned plants produced teeth on approximately the upper two thirds of the awn. While in this cross the rough vs. smooth-awn character appeared to be dependent on a single

factor difference, the degree of smoothness of the awn appeared to be dependent upon modifying factors which were apparently brought in by the rough-awned parent.

3. Some lines bred true in F_3 and in later generations for various degrees of smoothness of the awn, which would appear to justify the use of the hypothesis of modifying factors instead of the possible hypothesis of gene variability.

4. Black vs. white color was apparently dependent upon a single genetic factor which was inherited independently from the main factor difference for rough vs. smooth awn.

5. One hundred and twenty-four F_3 lines of the Manchuria-Lion cross were grown in rows of 25 plants each and sprayed with spore suspensions of *H. sativum*. Cultures of Lion and Manchuria were grown every tenth to twentieth row as checks. On the basis of the individual plant data for susceptibility or resistance, all F_3 lines were selected which appeared as resistant as Manchuria or as susceptible as Lion and were again tested in F_4. By this test 8 lines were obtained which were as susceptible in both F_3 and F_4 as Lion and 6 lines which were approximately as resistant as Manchuria.

6. The correlation coefficient for the degree of infection in F_3 and F_4 of 36 hybrid lines of Lion$\times$Manchuria was $.256\pm.105$.

7. The 36 hybrid families were tested for root infection under greenhouse conditions in 1922-23. The correlation coefficient for average severity of infection under field conditions for F_3 and F_4 as related to root infection under greenhouse conditions was $.426\pm.092$.

8. Resistance and susceptibility to attacks of *H. sativum* are inherited characters altho apparently dependent on more than a single genetic factor.

9. A greater proportion of the resistant families was of white color and rough awn than of the susceptible families; however, within the 124 F_3 lines grown, all combinations of resistance and susceptibility, smooth and rough awn, and black vs. white color were obtained.

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